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Review Article

A comprehensive review of robotic systems in modern dental care: Enhancing precision and reducing patient anxiety

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Abstract

Advancements in robotics have significantly transformed dentistry by offering innovative solutions that enhance patient care and clinical outcomes. This review explores the application of robotic systems in modern dental practice, focusing on anxiety reduction, improved precision, and increased procedural efficiency. Robots such as Medi Robot and iRobiQ support pediatric patients through interactive engagement, while Yomi and the da Vinci Surgical System enhance accuracy in implant and microsurgical procedures. RoboDent further improves precision in endodontic and implant treatments. As these technologies evolve, they promise a future of dental care that is more efficient, accurate, and patient-centered.

Keywords: *Robotics, dental care, anxiety reduction, pediatric dentistry, dental implants, precision, da Vinci Surgical System, Yomi, Medi Robot, RoboDent.*

Introduction

The successful integration of medical robots into healthcare has sparked growing interest in robotics within the field of dentistry, offering innovative solutions that break away from traditional oral diagnosis and treatment methods. This shift paves the way for new technological advancements in dental care. The integration of robotics into healthcare is transforming dentistry by enhancing precision, improving outcomes, and reducing patient anxiety especially in complex procedures like dental implants, microsurgeries, and endodontics. In pediatric dentistry, robots offer effective tools to ease anxiety in young patients. This growing adoption reflects a broader shift away from traditional methods, driving innovation across areas such as prosthodontics, oral surgery, implantology, orthodontics, and endodontics. This article reviews the development and applications of robotics in modern dental practice.

The role of robotics in dentistry spans a variety of technologies, each aimed at addressing specific challenges within the field. Robots such as the Medi Robot and iRobiQ have been designed to support pediatric patients by providing emotional comfort and distraction during treatments, significantly reducing dental anxiety. For more complex dental procedures, robotic systems like Yomi and the da Vinci Surgical System offer enhanced precision, allowing for more accurate implant placement and microsurgical interventions. In the realm of endodontics and implantology, RoboDent contributes to improved treatment outcomes by minimizing human error and enhancing procedural accuracy.

This review aims to explore the evolving role of robotic technologies in dental care, focusing on their application in reducing patient anxiety, enhancing procedural accuracy, and improving clinical outcomes. By synthesizing the current literature, this article highlights the potential benefits and challenges associated with the adoption of robotics in dentistry, while offering insights into future directions for research and practice.

As technology continues to advance, robotic systems are expected to become more integrated into everyday dental procedures, ultimately shaping the future of dental care and patient experiences. This article will examine key robotic systems, including Medi Robot, iRobiQ, Yomi, da Vinci, and RoboDent, and their impact on dental practice, patient care, and treatment outcomes.

1. Medi Robot: Calming Pediatric Anxiety

The Medi Robot is primarily designed for pediatric care and is widely used to manage dental anxiety in children. Serving as a companion robot, it engages young patients through conversation, games, and emotional support, offering a friendly and interactive distraction during dental visits. This reduces fear and stress, allowing dentists to perform procedures more effectively. While specific studies on Medi Robot are limited, similar humanoid robots have demonstrated measurable success in reducing anxiety and improving behaviour in children during dental procedures. Its use reflects a broader shift toward patient-centered care and emotionally intelligent technologies in modern dentistry.

2. iRobiQ: Interactive Education and Distraction

iRobiQ, developed by Yujin Robotics, is an interactive humanoid robot designed to support pediatric dental care by reducing anxiety and enhancing patient cooperation. are small, autonomous, and equipped with features like touch-screen LCD displays and multi-color LEDs. They can express emotions such as happiness, sadness, surprise, or anger, enhancing communication and engagement with content, music, videos, and child-friendly explanations of dental procedures. According to attentional capacity theory, for a distraction to be effective, it must be more engaging than the pain stimulus. Therefore, the interactive nature of humanoid robots may offer a promising avenue for reducing anxiety and pain perception in pediatric dental settings.

These features help distract and comfort children before and during treatments, significantly reducing stress and improving behavior. Clinical trials have shown that iRobiQ is effective in managing dental anxiety, with studies demonstrating notable improvements in cooperation among children aged 4 to 10 years.

Distraction techniques, particularly audiovisual distractions like computer games, television, and 3D video glasses, have been effective in reducing dental fear and anxiety in children. These methods are non-invasive, easy to apply, safe, and simple. However, some studies, such as by Brignardello-Petersen, suggest that audio visual distractions may not significantly improve behaviour or reduce pain during dental treatment.

In summary, while traditional behavior management techniques remain foundational, integrating advanced distraction methods like audiovisual tools and humanoid robots could enhance the effectiveness of pediatric dental care by reducing anxiety and improving patient cooperation.(1)

3. Yomi Robot: Precision in Dental Implantology

The Yomi robotic system, developed by Neocis, is the first and only FDA-cleared robot-assisted device for dental implant surgery. It offers real-time haptic guidance, visual feedback, and intraoperative flexibility, enabling clinicians to place implants with exceptional precision while minimizing surgical trauma. Unlike static surgical guides, Yomi maintains high accuracy even when adjustments are needed during the procedure. A landmark study published in *The International Journal of Oral & Maxillofacial Implants* reported angulation errors of less than 1.5 degrees and depth deviations under 0.2 mm, demonstrating Yomi's superior precision compared to traditional methods. Its adoption has also been associated with increased implant case volume and improved practice profitability, marking a significant advancement in the field of implant dentistry.

Robotics has become integral across various sectors, notably in medicine, where it has transformed surgical practices. Robotic-assisted surgeries offer enhanced precision, improved visualization, and reduced invasiveness, leading to quicker recovery times and minimized complications

In the realm of dental care, robotic systems have significantly impacted jawbone reconstruction and implant procedures. Over the past twenty years, extensive research has focused on integrating robotics into dental surgeries to improve accuracy and patient outcomes. Robotic dental systems are categorized based on the level of human interaction:

1. **Active Robots**: These systems, such as YekeBot from Beijing, operate autonomously to perform tasks like implant site preparation and placement, with minimal human intervention.
2. **Passive Robots**: Examples include Yomi from Miami and DentRobot from Suzhou. In these systems, the operator manually guides the robotic arm during the procedure, offering assistance without full autonomy.
3. **Semi-Active Robots**: Systems like Remebot from Beijing combine autonomous actions with operator guidance, performing certain tasks independently while requiring human assistance for others.

Studies indicate that active and semi-active robots demonstrate comparable accuracy in implant placement, whereas passive robots may exhibit higher deviations, highlighting the importance of human-robot interaction in surgical outcomes.

Advancements in Robotic-Assisted Dental Implant Surgery

Robotic technology has significantly transformed dental implant procedures, enhancing precision, efficiency, and patient outcomes. Various robotic systems have been developed to assist dental professionals in performing implant surgeries with greater accuracy and reduced human error.

1. YekeBot Dental Surgery Robot
Developed by Yekebot Technology Co., Ltd. in Beijing, China, YekeBot is an active robotic system designed to autonomously perform dental implant surgeries. The system features a robotic arm capable of entering and exiting the patient's mouth, preparing the implant site, and placing the implant according to pre-operative plans. The surgeon oversees the procedure, providing instructions and replacing instruments as necessary. This collaborative approach aims to enhance surgical precision and reduce the risk of human error.
2. Remebot Dental Surgery Robot
Baihui Weikang Technology Co., Ltd., also based in Beijing, has developed Remebot, a semi-active robotic system that assists in dental implant procedures. Remebot can autonomously perform certain tasks, such as preparing the implant site and placing the implant, while requiring the surgeon's assistance for other aspects of the procedure. This hybrid approach combines the benefits of robotic assistance with human oversight to ensure optimal surgical outcomes.
3. Yomi Dental Surgery Robot
Yomi, developed by Neocis Inc. in the United States, is a passive robotic system that assists dental surgeons during implant procedures. The system utilizes a coordinate measuring machine (CMM) arm to guide the surgeon's hand during surgery, providing real-time feedback and enhancing precision. Yomi has received FDA approval, indicating its safety and effectiveness in clinical settings.
4. DentRobot Dental Surgery Robot
Introduced by Dcarer Medical Technology Co., Ltd. in Suzhou, China, DentRobot is a passive robotic system designed to assist in dental implant surgeries. The system utilizes optical tracking technology and is controlled by the surgeon through a foot controller. DentRobot provides real-time guidance during the drilling process, ensuring accurate implant placement and enhancing surgical efficiency.
5. Theta Dental Surgery Robot
Developed by Hangzhou Jianjia Robot Co., Ltd. in 2023, Theta is a semi-active robotic system designed for dental implant surgeries. The system combines control buttons and an optical navigation system to enable precise positioning, drilling, and placement of dental implants. Theta's compact design and advanced capabilities aim to enhance the precision and efficiency of dental implant procedures.
6. Human–Robot Collaborative Implant System (HRCDIS)
HRCDIS is a semi-passive robotic system designed for human-machine collaboration in dental implant surgeries. The system incorporates a zero-force hand-guiding scheme and an operational task management system. Utilizing a visual position tracking system comprising an optical camera and positioning marker, HRCDIS accurately determines the positions of the robot arm and identifies the precise drilling location and direction. This collaborative approach enhances productivity and efficiency in dental implant procedures.
7. Langyue Dental Surgery Robot
Developed by Shecheng Co. Ltd., Langyue is a semi-active collaborative robot designed to assist dental surgeons during implant procedures. The system incorporates both autonomous and passive-triggered actions to optimize the surgical process. Langyue provides automatic angular control, allowing the surgeon to guide the drill forward or withdraw it, ensuring precise implant placement.
8. Hybrid Robotic System for Dental Implant Surgery (HRS-DIS)
HRS-DIS is a semi-active robotic system developed in Shanghai, China, designed to assist in dental implant surgeries. The system consists of a 5-degree-of-freedom (DOF) serial manipulator and a 6-DOF Stewart manipulator. The serial manipulator expands the robot's workspace, while the Stewart manipulator ensures precise positioning and stiffness. HRS-DIS aims to enhance the accuracy and efficiency of dental implant procedures through its advanced robotic capabilities. (2)

4. Da Vinci Surgical System: Minimally Invasive Oral Surgery

Originally developed for general surgery, the da Vinci Surgical System has been adapted for use in oral and maxillofacial procedures, offering significant advantages in precision and control. Featuring robotic arms, tremor reduction technology, and a high-definition 3D visualization system, it enables surgeons to perform complex oral surgeries—such as tumor resections and reconstructions—with enhanced dexterity and minimal invasiveness. These capabilities allow for more accurate operations in confined anatomical areas, contributing to faster patient recovery and fewer complications. While specific studies on dental applications are limited, the system’s proven success in various surgical disciplines highlights its promising role in advanced oral and maxillofacial treatments.

Robotic systems have significantly advanced dental implant procedures by enhancing precision, reducing human error, and integrating artificial intelligence (AI) for real-time decision-making. These systems are categorized based on their level of human interaction:

1. Active Robots: Fully autonomous, these robots perform tasks such as drilling and implant placement without human intervention. For instance, the YekeBot system operates independently, requiring the surgeon only to monitor and provide instructions.

2. Semi-Active Robots: These systems, like the Langyue robot, combine autonomous functions with human oversight. The robot performs certain tasks, but the surgeon guides and supervises the procedure, ensuring adaptability and safety.
3. Passive Robots: The surgeon manually controls the robotic arm, with the robot providing guidance and feedback. Systems such as Yomi and DentRobot fall into this category, offering enhanced precision through haptic feedback and real-time tracking.

In vitro studies have demonstrated that robotic systems can place implants with minimal deviations. For example, a systematic review reported mean global coronal, apical, and angular deviations of 0.7 mm, 0.8 mm, and 1.8°, respectively, in in vitro settings. Clinical studies have shown similar results, with deviations within clinically acceptable ranges

However, the integration of AI is poised to further revolutionize robotic dental surgery. AI algorithms can analyze cone beam computed tomography (CBCT) scans, design optimal implant treatment plans, and provide real-time assessments during surgery. This integration allows for dynamic adjustments, enhancing safety and efficiency.

Despite these advancements, challenges remain. Robotic systems are currently limited in performing complex procedures such as guided bone regeneration (GBR), sinus lifts, and soft tissue grafting. These tasks require human expertise due to the need for tactile feedback and adaptability to varying anatomical conditions.

In summary, while robotic systems have demonstrated enhanced accuracy and efficiency in dental implant procedures, ongoing research and development are essential to expand their capabilities. The future of dental surgery lies in the seamless integration of robotics and AI, offering the potential for more precise, efficient, and personalized patient care. (2)

5. RoboDent: Advanced Navigation in Endodontics and Implants

RoboDent is a robotic navigation system developed to enhance accuracy in dental implantology and endodontic procedures. By integrating advanced 3D imaging with real-time robotic guidance, it assists clinicians in achieving precise angulation and depth during surgeries, particularly in complex cases such as root canal therapy and multiple implant placements. This precision reduces the risk of human error, improves procedural success rates, and streamlines clinical workflow. While comprehensive studies on RoboDent remain limited, its technological capabilities represent a significant step forward in improving the quality and reliability of advanced dental treatments.

Conclusion

As robotics continue to evolve, their integration into dentistry is reshaping clinical practice by enhancing precision, safety, and patient comfort. From pediatric support robots like Medi Robot and iRobiQ to high-precision systems such as Yomi, da Vinci, and RoboDent, these technologies are revolutionizing dental care. Continued innovation promises a future where dental treatments are not only more accurate and efficient but also more accessible and patient-centered.

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